Birds of Prey: Training Solutions to Human Factors Issues

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ABSTRACT

The use of unmanned air vehicles (UAVs) in military operations is expanding rapidly, and this trend will likely continue given increases in funding for UAV development from $3 billion in the 1990s to over $12 billion for 2004-2009. High UAV mishap numbers have generated multiple reviews of unmanned operations in the past few years, but even within common platforms, different analysts attributed these mishaps to differing causes. Thirty Air Force Predator Class A mishaps (more than $1 million damage) occurred from the introduction of this system into the Air Force inventory in 1995 through the end of FY 2006. Reports were reviewed to identify trends. Substantial changes over time were observed regarding annual mishap rates, annual mishap counts, and causal factors. Mishap rates across the past three years dropped to less than one half the rate across earlier years. Mishap *counts*, however, steadily increased, as did Predator flying hours. Early mishap reports typically cited mechanical problems and operator station design issues. Mechanical problems were much less frequently cited in the last three years. Rather, 80% of recent mishaps cited causal human error factors. Equipment interface problems were still cited as causal or major contributing factors in almost half of recent mishaps. Recent mishap reports often cited shortfalls in skill and knowledge (checklist error, task misprioritization, lack of training for task attempted, and inadequate system knowledge), situation awareness (channelized attention), and crew coordination. These trends come in a period characterized by a rapidly growing crew force and highlight the need to revisit both individual and team Predator training objectives and consider alternative training interventions that focus on the practice and improvement of these key operator skill areas. Predator team coordination and situation awareness training objectives are also addressed for the command and control personnel with whom Predator crews interact.

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14. ABSTRACT

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15. SUBJECT TERMS

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INTRODUCTION

The Department of Defense (DoD) dictionary (Joint Pub 1-02) defines unmanned aerial vehicles (UAVs) as "powered aerial vehicles that do not carry a human operator, use aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and carry a lethal or non-lethal load." While early attempts to apply such technology for military purposes can be traced back to World War II or before (Gambone, 2002), UAVs clearly entered the mainstream of combat operations during recent conflicts in Kosovo, Afghanistan, and Iraq.

In these recent conflicts, UAVs were typically used as Intelligence, Surveillance, and Reconnaissance/Target Acquisition assets, providing commanders with imagery intelligence, electronic intelligence, and streaming video. Resulting information could be used to direct fighter aircraft to their targets, monitor enemy movements, and conduct battle damage assessment. The Predator system added the strike mission to its repertoire, and plans for similar capabilities in other DoD UAVs are not far behind. Additional roles include homeland security (e.g., border patrol), long-duration law enforcement surveillance, and delivery of critical medical supplies needed on the battlefield (Bone and Balkcom, 2003). The Quadrennial Defense Review (Office of the Secretary of Defense, 2006) emphasized that approximately 45% of the future long-range strike force will be unmanned and that there would be a clearly-defined need to double the UAV coverage capacity by accelerating the acquisition of Predator UAVs. Predators entered the Air Force inventory in 1995, and flying hours increased rapidly, expanding more than twenty-fold in the decade from 1997 to 2006 (Air Force Safety Center, 2007). Despite this rapid growth, only about one third of requests for Predator surveillance can currently be met, with growth in flying hours being limited by the ability to train enough crews to meet this demand in Afghanistan and Iraq (Brook, 2007). Increases in planned funding are even steeper in the next few years (Bone and Balkcom, 2003). UAVs are predicted to dominate the battlespace in the 21st century and will include intelligent, autonomous systems of systems that are expected to conduct a myriad of missions from surveillance and reconnaissance to suppression of enemy air defense and precision strike.

While there is considerable demand for UAV support, the rapid rise in UAV employment has been accompanied by high mishap numbers. Tvaryanas, Thompson, and Constable (2005) conducted an in-depth review of UAV mishaps across the United States military services. They reported that, since the inception of the systems through the end of FY 2003, 334 mishaps per 100,000 flying hours occurred with the Navy/Marine Corps Pioneer, 55 mishaps per 100,000 flying hours occurred with the Army's Hunter system, and 32 mishaps per 100,000 flying hours occurred with the Air Force's Predator system. For comparison purposes, overall Air Force Class A mishap rates ($1 million damage or fatality) are typically in the low single digit range per 100,000 flying hours (O'Toole, Hughes, & Musselman, 2006). It should be noted that most manned aircraft are mature systems, while most UAV programs are relatively early in their life cycles, and mishap rates tend to improve with system maturity. Additionally, many UAV systems did not undergo a classic acquisition, development and fielding program. Many were fielded directly from development into operational duty.

Several senior reviewers have drawn negative implications for UAV affordability and mission availability from these high initial mishap rates. An Office of the Secretary of Defense UAV reliability study (2003) concluded that it was critical to improve UAV reliability because affordability, availability, and acceptance are all linked to reliability. A Defense Science Board Study on Unmanned Aerial vehicles and Uninhabited combat Aerial Vehicles (2004) concluded

that UAV programs have not yet expended the resources necessary to fix the root causes leading to mishaps, and that manned-aircraft-like reliability is achievable, but will require substantial additional investment. A recent challenge from the Secretary of Defense to reduce the numbers of mishaps by at least 50% also focused attention on UAV mishap frequencies. In the Air Force, 20% of Class A mishaps in FY 2004-2006 involved UAVs, a percentage that remained constant across all three years.

A consistent picture of the problem to be solved has not yet emerged for UAV mishap reduction. Even at basic levels such as the relative contributions of equipment failure versus human error, different analysts reached widely differing conclusions. The Defense Science Board (2004) reported that 17% of UAV mishaps were attributable to human error, while Tvaryanas and his colleagues (2005) reported that 68% of mishaps involved causal human factors. An Office of the Secretary of Defense Reliability Study (2003) reported that human error represented 16% of all sources of Predator A (MQ-1) system failures and 2% of Predator B (MQ-9) mishaps, while Williams (2004) reported that 67% of Predator mishaps involve human factors. Some researchers looked at Class A (more than $1 million damage or a fatality), B (more than $200,000 damage, and C (more than $20,000 damage) mishaps (e.g., Tvaryanas, 2006), some considered Class A mishaps only (Williams, 2004), and others did not specify the scope of the mishaps analyzed.

Experience with previous efforts to reduce mishaps in manned aircraft dictates that successful interventions to improve reliability must be based on an accurate understanding of the root causes leading to failure. Several researchers recently documented differing root cause patterns across organizations and platforms. Helmreich, Wilhelm, Klinect, and Merritt (2001) studied threats to safety and the nature of errors in three domestic air carriers in the United States, and striking differences were observed among these airlines regarding both threats to safety and operator errors despite obvious commonality with respect to mission and environment. Nullmeyer, Stella, Montijo, and Harden (2005) reported differing mishap root causes across Air Force manned aircraft types. Williams (2004) reported major deviations in root causes across UAVs, and Tvaryanas, et al. reported significant differences among root causes depending on the service involved.

Based on rapidly increasing UAV operations, the emphasis from senior military leaders on reducing UAV mishaps, and the lack of consensus in the literature on causal factors, we felt that root cause analyses are needed to assess the role that training interventions could play to reduce mishaps and increase capability for a given platform. Our focus in this paper is on root causes and other characteristics of the 30 Air Force Predator Class A mishaps that occurred from FY 1997 through the end of FY 2006. This initial focus was chosen in part because Class A mishap reports are more detailed than Class B or Class C mishap reports, and in part because Class A mishaps have evolved as highly visible metrics of safety and reliability. Based on the patterns that emerged from these analyses, training interventions are proposed to address the areas of greatest potential gain.

METHODS

Class A flight mishaps (more than $1 million damage or a fatality) are usually investigated by two groups, a Safety Investigation Board (SIB), and an Accident Investigation Board (AIB). The primary purposes of safety investigations are to provide timely assessments of possible force-wide implications on the combat readiness of the systems involved and to find causes in order to prevent future mishaps. Safety investigation reports include facts, board analyses, findings, causes, and recommendations. The AIB reviews the factual information reported in the safety investigation report, gathers additional information as deemed necessary, and provides a report for public release that includes the Board President's opinion about what caused the mishap. The AIB report may also describe factors that are believed to have contributed to the mishap. Both SIB and AIB data were reviewed regarding the 30 Air Force Predator Class A mishaps that occurred from the time the system entered the Air Force inventory in 1995 through the end of FY 2006.

Primary Data Sources

The United States Judge Advocate General's office maintains an online repository of AIB report summaries for Air Force Class A mishaps. This site (http://usaf.aib.law.af.mil) is publicly accessible, lists Class A mishaps by fiscal year across the Air Force, and provides one page executive summaries of AIB reports as they are released. Contents include a description of the mishap, a discussion of probable cause, and recommendations.

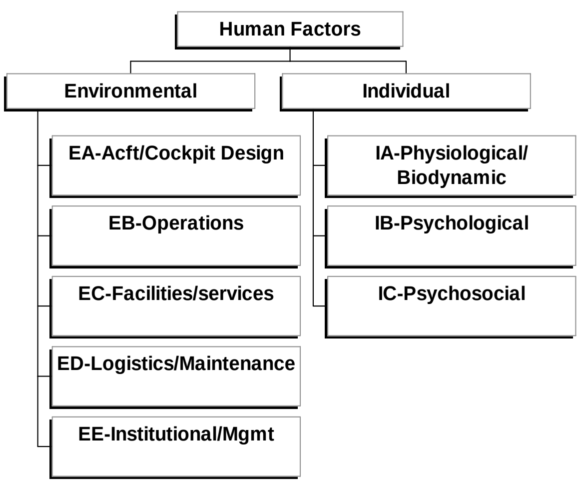
Mishap data are available from the Air Force Safety Center at varying levels of granularity. The analyses reported here considered information from four distinct Safety Center data sources. Moving from general to specific, the first was statistical data from the Air Force Safety Center web site (http://afsafety.af.mil). These

data include hours flown and numbers of Class A mishaps by fiscal year and by aircraft type.

The second data source was safety investigation summaries. These documents, a few pages long, provided a brief narrative of the mishap, and categorized the 30 Predator Class A mishaps as being logistics-, maintenance-, or operations-related. Summaries also provide descriptive data for each mishap such as phase of the mission and time of day in which the mishap occurred. Finally, conclusions and recommendations were listed.

The third source of data was a detailed **Human Factors Database** that is maintained by Safety Center Life Sciences analysts. Through 2006, analysts used the *Mishap Human Factors Taxonomy* to structure findings regarding the roles played by operators, maintainers, and other personnel. This taxonomy divides human factors into two major branches--environmental or individual factors. These two branches are further subdivided as shown in Figure 1.

Figure 1: Mishap Human Factors Taxonomy



Each area is, in turn, further divided into sub-areas. For example, "Operations" includes mission preparation, cockpit/crew resource management training, procedural guidance/publications, and mission demands. Finally, several elements comprise each sub-area, resulting in over 360 detailed elements that are available to catalog mishap human factors. Each factor cited is assigned a weight using the following scale: (4)-causal; (3)-major factor, (2)-minor factor, (1)-minimal factor, or (0)-present but not a factor.

The fourth and most detailed data source in the current analysis was discussions of human factors from the full mishap investigation reports. **SIB Findings** are formally documented as one section of the full mishap report. These findings were reviewed for descriptions of human factors causing or contributing to the mishap. In addition to the board findings, a separate **Life Sciences Report** is prepared by the Life Sciences Branch of the Air Force Safety Center. The Life Sciences Report provides a chronological mishap narrative and a discussion of every human factors database element cited. Interrelationships among the human factors may be addressed.

Analytic Approach

AIB summary reports and Safety Center summary statistics were initially analyzed to generate descriptive trend data regarding mishap frequencies, mishap rates, and the general nature of mishaps (equipment failure, maintainer error, or operator error) over time. Mishap frequency and flying hour data were obtained from the Air Force Safety Center web site (http://afsafety.af.mil). Data regarding probable cause were obtained from the Air Force Judge Advocate General Corps web site (http://usaf.aib.law.af.mil). We completed our overall trend analyses by assigning each Predator Class A mishap to the phase of flight in which it occurred based on data from Safety Center mishap summaries.

The specific human factors elements cited in Predator Class A mishaps were obtained from the Air Force Safety Center human factors database. This database lists all human factors cited in the Life Sciences Report section of each full mishap report and provides a weighted score: 4=causal, 3=major factor, 2=minor factor, 1=minimal factor, and 0=present but not a factor. From this database, we determined both frequencies of occurrence and levels of contribution associated with each detailed human factors element. Sums of weighted factors were calculated across mishaps for each Human Factors Taxonomy element cited. These weighted sums were used to rank-order the individual elements. Most of the detailed elements that were cited fit into seven general categories: operator interface issues, skill/knowledge, documentation, planning/ preparation, and organizational or management issues. As an example, crew coordination, crew composition, intracockpit communication and subordinate style were combined to form the teamwork category. These groupings allowed identification of trends among similar individual factors.

The human factors database also guided subsequent reviews of the Life Science Reports since every factor cited in the database was discussed in the full reports. Qualitative analyses of these discussions were accomplished to gain a better understanding of the

underlying behaviors that led to each element being cited. There is considerable risk of misinterpretation if database quantitative analyses are accomplished without reviewing the descriptive content of the associated Life Sciences Division reports.

RESULTS

Predator flying hours per year increased substantially over the time period covered in this analysis (Figure 2) as reported on the Air Force Safety Center Web site (http://afsafety.af.mil). Annual flying hours increased from less than 3000 in 1997 to almost 60,000 in 2006. Projections call for continuing increases in UAV operations. These changing utilization levels are important to consider when interpreting trends in mishap frequencies over time. Predator mishap frequencies also increased over fiscal years as shown in Figure 3 (http://usaf.aib.law.af.mil, 2007), with fiscal years accounting for over 65% of the variability observed in mishap frequencies (correlation = .81, $p < .001$). The primary cause of the mishaps appears to be shifting over time. Causes in AIB reports were normally stated in terms of equipment failure, operator error, or a combination of the two and are depicted by fiscal year in Figure 3. Mishaps in the first few years were often attributed to equipment failures, while mishaps in the past three years were predominantly attributed to operator error. A similar pattern was seen in Safety Center mishap summaries. Fifteen mishaps occurred between 1997 and 2003, and 15 additional mishaps occurred between 2004 and 2006, where a statistically significant change was seen from the first 15 mishaps being attributed primarily to problems not related to operators (logistics or maintenance) to mishaps being attributed primarily to operator error in the most recent 15 mishaps (chi square = 5.40, df = 1, $p < .02$). In Safety center analyses, nine of the first 15 mishaps were attributed to equipment factors, and even four of the six operator-error mishaps cited causal equipment interface problems. In total, thirteen of the fifteen mishaps from 1997 through 2003 cited causal equipment factors. In the second half, one mishap was attributed to equipment failure and the remaining 14 were attributed to operator (12 mishaps) or maintainer (2 mishaps) error. Further, only three of the 11 mishaps attributed to operations cited equipment as a causal factor. Functional design continued to be cited as a contributing factor, however, in many of these recent mishaps. Finally, UAV mishaps represented approximately 20% of all Air Force Class A mishaps in each of the past three years (http://usaf.aib.law.af.mil).

Predator mishap rates per 100,000 flying hours, on the other hand, decreased substantially over the same time period (Figure 4). Despite comments from some reviewers of unusually high mishap rates in UAV systems, Predator mishap rates are following a pattern that is very similar to the rates seen early in the history of the F-16 weapon system, which also encountered both mechanical and human error problems early in its life cycle. F-16 mishaps are now very close to overall Air Force mishap rates. In Figure 4, both the predator and the historic F-16 mishap rates depicted start with the first year in which more than 5000 hours were flown annually in that platform. For F-16 mishaps, the data points represent the time period between 1977 and 1984. For comparison purposes, the overall Air Force mishap rate has been slightly less than two mishaps per 100,000 flying hours for the past decade or more.

Figure 2: Predator Hours Flown

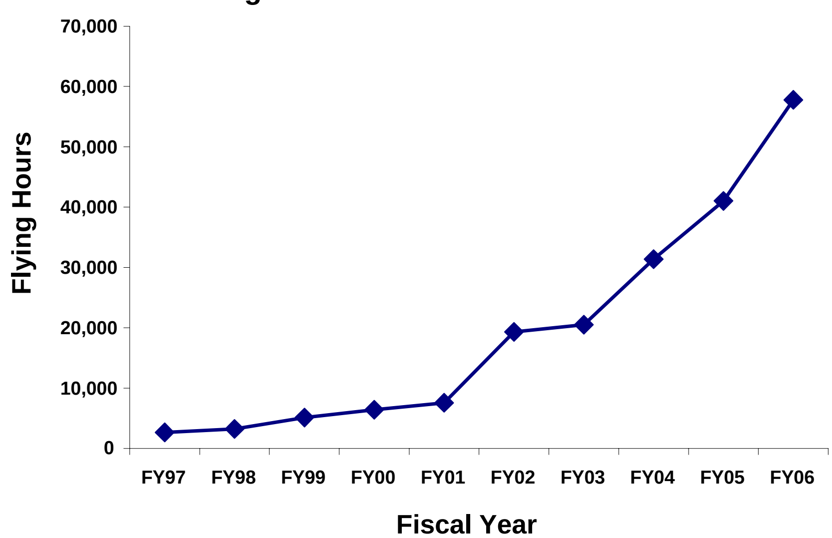
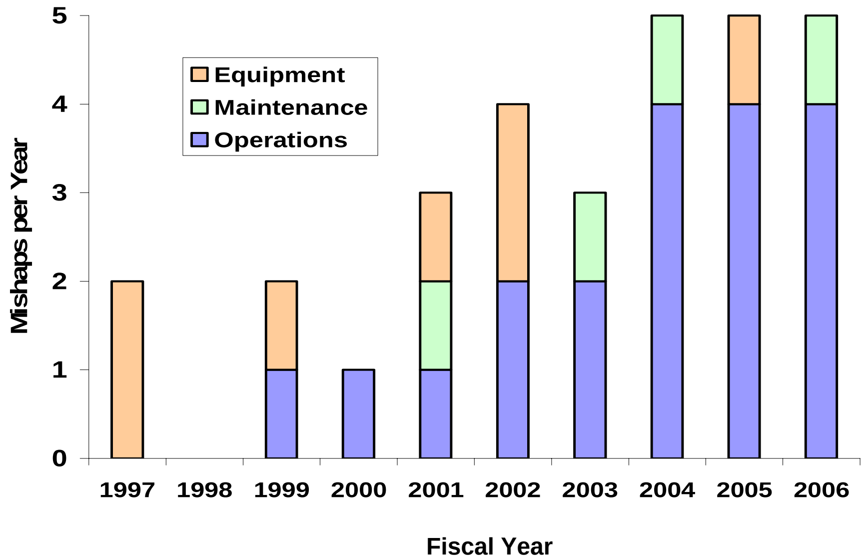


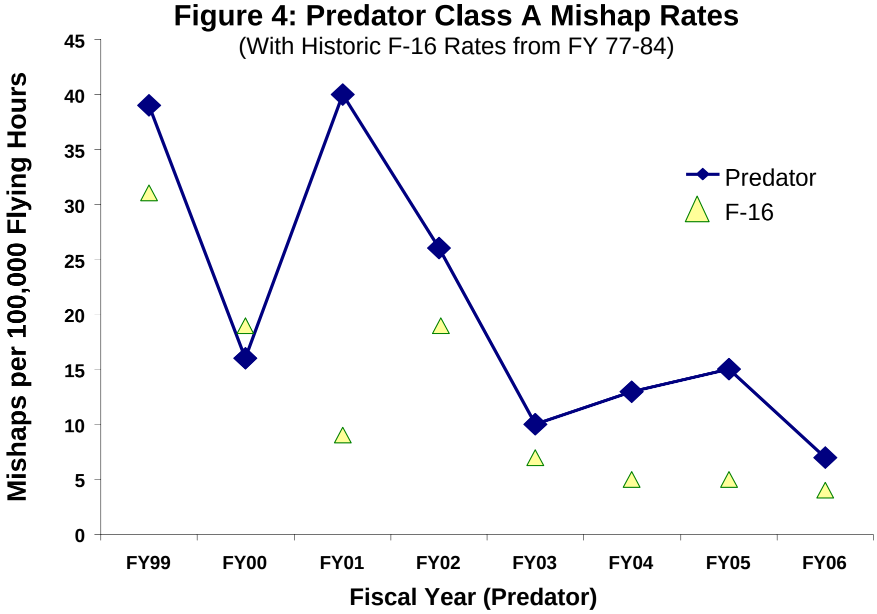
Figure 3: Predator Class A Mishap Frequencies and Causes
(http://usaf.aib.law.af.mil)



Safety Center mishap summaries were reviewed to identify the mission phases in which the mishaps occurred. Results are shown in Figure 5. The sequence of events leading to the Class A mishaps started during the enroute phase of the mission more than two thirds of the time. It should be noted that Predator missions may last many hours, and with respect to elapsed time, this phase accounts for a huge proportion of the hours flown. Of some interest, both equipment failures and human error were well represented in this phase. Most other mishaps occurred in the final approach and landing phases of the mission, and these typically involved operator error.

We next analyzed the specific human factors elements that were cited in Safety Center Class A mishap reports. Approximately 360 specific elements comprised the human factors taxonomy summarized in Figure 1. This taxonomy was used by the Safety Center during the time period of interest (FY1997-2006). Analysts used 72 of these 360 potential elements to capture the human factors associated with the 30 Class A Predator mishaps that occurred through the end of 2006. Each human factor cited was accompanied by a weighting that reflected the level of contribution of that factor to the outcome (4 = causal, 3 = major factor, 2 = minor factor, and 1= minimal factor).

Figure 4: Predator Class A Mishap Rates
(With Historic F-16 Rates from FY 77-84)

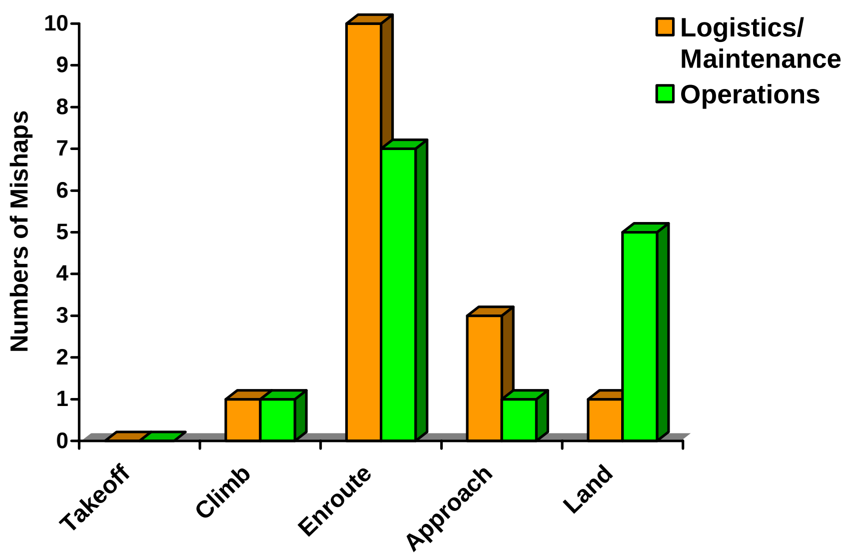


For each individual taxonomy element, numbers of mishaps where that element was cited were combined with factor weightings to develop a prioritized list of underlying factors. The top ten elements are listed in Table 1. Major, minor, and minimal factors were combined to form the contributing factor counts. Of the 30 total mishaps, the Safety Center attributed 17 to operations. Each of the 17 reports of operations-related mishaps cited multiple human factors, and several cited multiple causal human factors.

Many of the individual taxonomy elements cited in Predator mishaps appeared to be highly related. For example, two commonly cited individual factors listed in Table 1 were *channelized attention* and *inattention*. Both of these seem to reflect insufficient awareness of the operating environment. Further review of individual human factors revealed that most factors cited could be accommodated using seven higher-order categories: (1) equipment-related issues such as functional design, operator interface, and software logic; (2) decision making and risk assessment; (3) operator skills and knowledge; (4) situation awareness; (5) teamwork; (6) documentation such as technical orders and written procedures; and (7) mission preparation activities.

Given the magnitude of changes in mishap rates over time, it seemed reasonable to see if some early factors had been resolved. To do this, a first half/second half comparison was accomplished on the human factors cited in Predator Class A mishaps. Figure 6 shows the frequencies with which elements from the eight categories were cited as causal or major contributing factors in the first 15 Predator mishaps, which occurred from FY 1997 through the end of FY 2003. Equipment interface issues were the most commonly cited human factors in these early mishaps, followed by situation awareness factors, decision making or risk assessment, and lack of adequate written procedures.

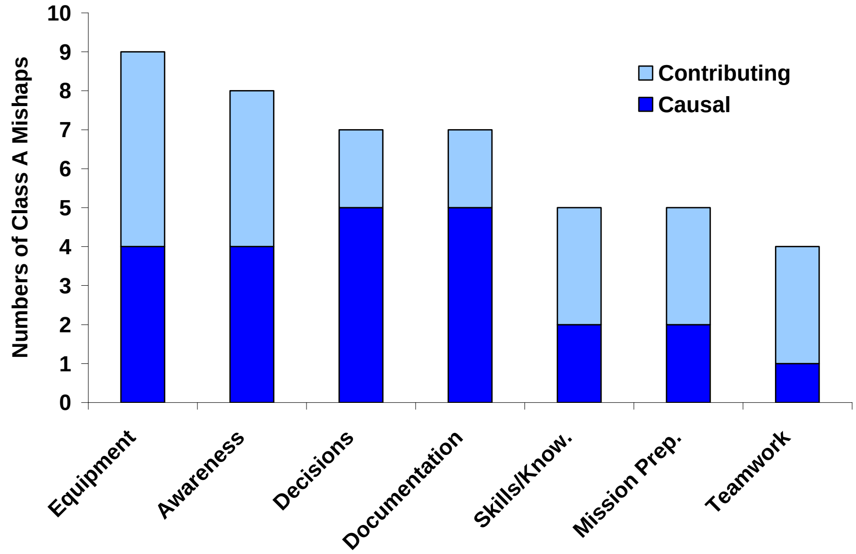
Figure 5: Predator Class A Mishaps by Mission Phase



Individual Factor	Area	Causal	Contributing
Written Procedures	Documentation	5	6
Channelized Attention	Situation Awareness	4	5
Functional System Design	Equipment	4	4
Checklist Error	Skill/Knowledge	3	3
Crew Coordination	Teamwork	2	4
Course of Action Selected	Decision Making	4	1
No Training for Task	Skill/Knowledge	1	4
Inattention	Situation Awareness	2	3
Task Misprioritization	Skill/Knowledge	1	4
Automation	Equipment	2	2

Table 1: Top Ten Detailed Mishap Factors

Figure 6: Early (1997-2003) Mishap Factor Categories
(9 Operations-Related Mishaps)



Causal and major contributing factors cited in more recent 15 Predator Class A mishaps (FY 2004 - 2006) are summarized in Figure 7. The major categories remained the same as those in the earlier mishaps, but there appeared to be some shifts of emphasis among the categories. Equipment and decision making factors were still frequently cited, but usually described as contributing to causal operator error. There was a substantial increase in instances where skill/knowledge and teamwork issues were judged to be causal compared to the patterns seen in earlier mishaps.

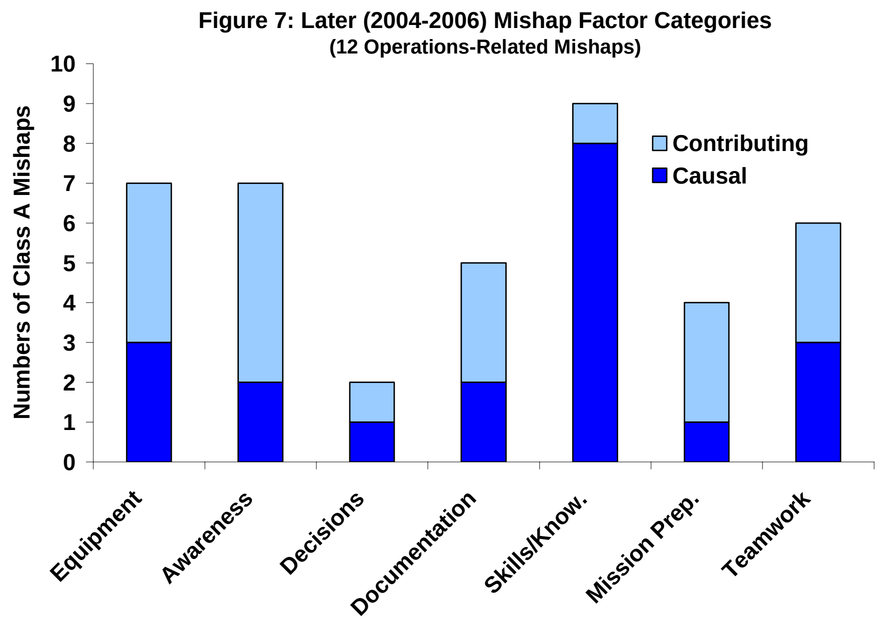
Specific elements contributing to increased skill and knowledge factors were crews not properly following checklists, no training for task attempted, inadvertent inputs to the Predator through the operator station, and limited total experience. Lack of written procedures, functional design issues associated with controls and displays, and lapses in getting software change notices to crews frequently contributed to these mishaps.

Teamwork issues involved several failures of the pilot to react to inputs from the sensor operator or a lack of one crewmember to back up another. Several involved confusion between instructor pilots and student pilots regarding who had control of the aircraft. In several cases, there is no written procedure regarding roles, especially when troubleshooting. Until recently, simulation did not support crew-level training.

DISCUSSION

Predator mishap trends reflected systematic and substantial changes over time. The overall direction of Predator mishap trends depends on the measure used. Mishap frequencies steadily increased over time as have Predator hours flown, while mishap rates decreased substantially (from 23 Class A mishaps per 100,000 flying hours from fiscal years 1997-2003 to less than 11 in fiscal years 2004-2006). Predator mishap rates remain high relative to more mature Air Force weapon systems, but they are similar to the rates seen in the early years of F-16 operations and are dropping quickly. We believe that mishap rates are the most relevant global trend data. While rates are still high, they are moving toward the rates seen in other, more mature Air Force platforms. With respect to why Predators crash, a steady shift was observed from equipment failures to human error. In the past three years, we found a substantial increase in mishaps that cite a lack of the operator skills and knowledge needed to successfully cope with the events encountered in real world operations.

The threat and error management model (Helmreich, et al, 2001) is widely used by air carriers to enhance safety. It also provides a reasonable structure for improving UAV mishap rates in military operations and ultimately for increasing combat capability. A key part of this approach is to use evidence to structure interventions that are tailored to alleviate the specific problems that actually plague a particular community. Training is one of several tools that can be used to meet safety and capability objectives, but other changes such as equipment modifications and adapted procedures may also be integral parts of an effective overall error mitigation strategy. The bottom line is that the better we understand threats to safety, the more successful



we are likely be in developing effective strategies to mitigate human error. Mishap trends to date appear to reflect two separate generations of factors—equipment failures in the early years followed by a series of human error mishaps spanning the last three years. A third generation of Predator training opportunities will likely accompany the move by all services toward network-centric warfare (NCW).

Attention was drawn to the first generation of threats to safety by early reviewers who voiced concerns about reliability of Predator power plants and other aircraft systems. With the vast majority of early mishaps attributed to such equipment failures, this was reasonable and accurate. Trends over the past decade suggest that these early risk reduction efforts are paying off—mishap frequencies *and* rates due to equipment failure have both steadily improved. Operations-related mishaps are driving current mishap counts and rates, but four Predator mishaps were attributed to maintainer errors including two in the last three years. Threat and error management is not just an operator issue. There is growing recognition that human factors training for maintainers has merit, and is often referred to as maintenance resource management.

Mishap trend data suggest that the Predator community has entered a second generation of mishaps, now fueled by operator error. Can these human error causes be addressed by training? The implications for training run the gamut from the way they are trained to what type of training they receive.

Personal observations over the past 5 years indicate a decrease in the experience levels of Predator aircrews. During the early establishment of the Predator weapons system, when crew resource management (CRM) training was conducted, the aircrews were generally very experienced in their previous weapons systems. Pilots had at least two if not three or more tours in a particular weapons system. Sensor operators were generally of mid-level rank and had at least two previous assignments, many of them aviation related, prior to coming to the Predator. Starting in 2004, Predator CRM training went from approximately 60 per year to over 100 and doubled again in FY 2006 to 216 students per year. From personal interviews and observations, the experience level of an average pilot is now one operational tour, and at least 50 percent of new sensors came directly from basic training.

Predators are operated by two kinds of teams. A launch and recovery team accomplishes take offs, approaches, and landings, while a mission crew handles the enroute surveillance, reconnaissance, target acquisition, and potentially, attack functions. An exception to this pattern is formal training sorties, when all mission phases are accomplished by one instructor and student crew. The mishap trends suggest that there is ample opportunity to improve performance in both teams.

Predator Class A landing mishaps, generally involved bounced landings with damage to the landing gear and sensor ball with resulting damage being in excess of reporting limits for a Class A mishap. Control delays,

narrow field of view, and the software interface between the ground control station and the air vehicle are all significant threats to safety that are faced by launch and recovery crews. Of some interest, all Class A landing mishaps have occurred in the past three years, suggesting that a review of changes in selection, training, or operating procedures may pay dividends. This period also coincides with the rapid expansion in the Predator weapons system, when the number of Predator crews more than doubled. Perceptual errors and pilot-induced oscillation are frequently discussed. In addition, lapses of judgment often appear in the form of continuing a marginal attempt to land when a go-around was the better choice.

The enroute portion of flight is the most likely mission phase for Class A mishaps to occur. Both equipment failure and operator error are most likely to result in a Class A mishap enroute. The large amounts of time spent in this phase undoubtedly contribute to the high proportions of mishaps. This is also where the "meat" of the mission occurs and activity levels and mission types can vary widely. This phase can range from routine, such as orbiting for hours watching a target with no appreciable activity, to a high intensity period launching Hellfire missiles in an urban close air support scenario. Aircrews also spend a large amount of time transiting between various targets and responding to short notice requests by ground assets for immediate surveillance. Supervisory control issues such as the use of autopilot hold modes and changing preprogrammed waypoints appear frequently in discussions of enroute Class A mishaps.

Current Predator syllabus training leads to a basic qualification to operate the weapons system for the "enroute" phase of flight. Takeoff and landing qualifications are accomplished at a later date. A qualified crew in theater normally accomplishes the takeoff and hands the Predator off to the mission crew for the actual operational mission and then receives the aircraft back for the landing. Additionally, other qualifications such as Air Strike Control and Close Air Support are added with "top-off" training. These are complex applications of the weapons system and performance is probably highly influenced by a pilot's previous operational experience. Some pilots may have little or no experience in the type of mission flown by the Predator (e.g. tanker or cargo pilots), which is likely to have a major impact on training requirements.

Many operator errors leading to Predator mishaps are associated with AFI 11-290 CRM skills, including task management, situation awareness, decision making, and crew coordination (teamwork). Research has shown that these skills can be improved with targeted training (Salas, et. al, 2006). Currently there is an on-going research effort to further refine the specific behaviors involved in these mishaps and more importantly develop associated training solutions to improve performance. There are many potential training programs and exercises that can teach aircrews about distraction, inattention, channelized attention, task prioritization, checklist management, decision making/risk management, and crew coordination.

The mishap factor category that has shown the largest increases over time is skill/knowledge. While this has been traditionally associated with task management under Air Force CRM definitions, there are other implications for training in this area as well. The current Predator training syllabus most likely needs improvement to bolster the minimum required knowledge to operate the Predator weapons system. Whether this takes the form of additional classes, more in-depth classroom study, self study, additional computer based training, or additional testing is best determined by further analysis.

The third generation is to move Predator training beyond a two-person domain and provide a more realistic representation of the real world. The Air Force web site (www.af.mil), defines the Predator system as follows: "The MQ-1 Predator is a system, not just an aircraft. A fully operational system consists of four aircraft (with sensors), a ground control station, a Predator Primary Satellite Link, *and approximately 55 personnel* for deployed 24-hour operations." Beyond this large team, Predator operations are part of a much larger command and control network.

The emergence of skill, knowledge, and teamwork factors leading to Predator mishaps suggests these same skill, knowledge and teamwork issues are present more broadly in Predator operations. Especially given the frequency with which mishap reports cite lack of training for task attempted, a training architecture to address these same issues within the larger command and control environment seems to make sense. A key element of this architecture is a training environment that includes sensor feeds and interactive simulations to increase knowledge, build teamwork, and hone critical decision-making skills. The adverse trends in operator error and crew coordination could be used to shape decision-making skills through NCW-command/ control scenarios. Effective command and control is inherently an iterative decision-making process as feedback from the battlespace is incorporated into plans and corrective actions. Warfare has always been a challenging domain characterized by the importance of the endeavor, risk to life, sheer magnitude of effort, and management of uncertainty.

While approaches to command and control have been honed over time to include improved training, there still lacks a training environment to exercise the entire network. Information Age-driven changes present us with a host of new command and control challenges. These changes challenge our most basic assumptions about command and control based on a doctrine developed from a different time to solve a different problem. One of the most enduring lessons derived from the history of warfare is the degree to which fog and friction permeate the battlespace. The fog of battle is about the uncertainty associated with what is going on, while the friction of war is about the difficulty in translating the commander's intent into actions. Much of the fog of war, or what is referred to today as the lack of battlespace awareness, have resulted in our inability to tap into our collective knowledge, or the ability to assemble existing information, reconcile differences, and construct a common picture. There needs to be equal emphasis placed upon developing a current awareness of both friendly and enemy dispositions and capabilities, as well as increased emphasis on neutrals.

In summary, high UAV mishap rates have generated much high level attention. Our review of Predator Class A mishaps revealed that most recent mishaps involve a limited range of threats to safety and a manageable set of causal and contributing human factors. These results suggest that training can be focused on solving a finite set of human performance problems. Human factors trends suggest that training is becoming an increasingly crucial tool for reducing mishaps. The solution will likely involve revisions to formal school syllabus content as well as to sharpening the focus of targeted human factors training. While operator error is commonly cited in Predator mishaps, value is also apparent in maintenance resource management training. Finally, the next logical step is to readdress teamwork training for the larger command and control team in which Predator crews operate.

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